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**SEARCH FOR EXOTIC BARYONS
WITH THE SPHINX FACILITY**

SPHINX Collaboration (IHEP-ITEP)

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Abstract

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In the experiments at the SPHINX facility in the proton beam of the IHEP accelerator ($E_p=70$ GeV) a number of diffractive production reactions were studied. Among them are $p + N \rightarrow (K^+ K^- p) + N$, $p + N \rightarrow (\phi p) + N$, $p + N \rightarrow [\Lambda(1520)K^+] + N$, $p + N \rightarrow [\Sigma(1385)^0 K^+] + N$, as well as some other processes. The results of the search for narrow heavy baryon states, candidates for the cryptoexotic hadrons with hidden strangeness, are presented.

Аннотация

Лаядсберг Л.Г. Писки экзотических барионов на установке СФИНКС: Препринт ИФВЭ 93-100. – Протвино, 1993. – 12 с., 5 рис., 1 табл., библиогр.:15.

В опытах на установке СФИНКС на пучке протонов ускорителя ИФВЭ ($E_p=70$ ГэВ) исследовались многочисленные процессы дифракционного образования барионных систем и, в частности, реакции $p + N \rightarrow (K^+ K^- p) + N$, $p + N \rightarrow (\phi p) + N$, $p + N \rightarrow [\Lambda(1520)K^+] + N$ и $p + N \rightarrow [\Sigma(1385)^0 K^+] + N$. Приводятся результаты поисков образования узких тяжелых барионных состояний в этих реакциях, являющихся кандидатами в криптоэкзотические барионы со скрытой странностью.

1. INTRODUCTION

In the experiments of the SPHINX Collaboration a wide program of studying the hadron diffractive production by protons with $E_p=70$ GeV and search for exotic baryons in these processes are carried out. This program has been detailed in Refs.[1,2]. Here are presented the first results of measuring the reactions

$$p + N \rightarrow (K^+ K^- p) + N, \quad (1)$$

$$p + N \rightarrow (\phi p) + N, \quad (2)$$

$$\quad \quad \quad \hookrightarrow K^+ K^-$$

$$p + N \rightarrow [\Lambda(1520)K^+] + N, \quad (3)$$

$$\quad \quad \quad \hookrightarrow pK^-$$

$$p + N \rightarrow [\Sigma(1385)^0 K^+] + N \quad (4)$$

$$\quad \quad \quad \hookrightarrow \Lambda\pi^0$$

$$p + N \rightarrow [\Sigma(1385)^0 K^+] + N + (\text{neutral particles}), \quad (5)$$

$$\quad \quad \quad \hookrightarrow \Lambda\pi^0$$

(N is nucleon or light nucleus — C , Be).

As it is stated in a number of papers, the diffractive production processes with Pomeron exchange offer some new possibilities to search for exotic hadrons [1-5]. This is specially true for the searches of heavy hadrons

with anomalously small decay width that can be serious candidates for cryptoexotic states. There were obtained some evidences of possible existence of such states — mesons $X(1740)$ [6], $U(3100)$ and $M_\phi(3250)$ [7,8], baryons $N_\phi(1960)$ [9], $\Sigma(3170)$ [10], $R(3520)$ [11] and several other hadrons. Thus systematical searches for such baryons with hidden strangeness in reactions (1)–(5) in the not very well known mass region of $\sim 2 \div 4$ GeV seems quite desirable.

The Pomeron exchange mechanism in diffractive production reactions opens the possibility to study the coherent processes on the target nuclei. It has been suggested that coherent production on nuclei is a good tool for the separation of resonances against multiparticle background because of the difference in their absorption in the target nuclei (see, for example, Ref.[12]).

The SPHINX facility [2], which was used for these measurements, includes a wide-aperture magnet spectrometer with scintillation counter hodoscopes, proportional chambers, drift chambers and multichannel γ -spectrometer with lead glass detectors. The charged particles in the final state were identified by means of RICH differential Cherenkov spectrometer and two threshold gas Cherenkov hodoscope counters. The experimental details connected with the accelerator runs, data handling and the methods of selecting reactions (1)–(5) can be found in Refs. [2,13–15].

As is seen from event distributions dN/dP_T^2 for reactions (1)–(5) as functions of the transverse momentum squared, there are considerable contributions of coherent diffractive production of pK^+K^- , ϕp , $\Lambda(1520)K^+$, $\Sigma(1385)^0K^+$ systems on the carbon nuclei. These coherent processes are characterized by slopes $b \gtrsim 30 - 40$ GeV $^{-2}$.

Below we have summarized the main physical results obtained in the SPHINX measurements.

2. SEARCH FOR HEAVY EXOTIC BARYONS WITH HIDDEN STRANGENESS IN REACTIONS (1)–(3)

In the invariant mass spectra of K^+K^- and pK^- systems in (1) clear peaks for ϕ -meson and $\Lambda(1520)$ baryon are obtained and reactions (2) and (3) are singled out. In the mass spectra for ϕp system in (2) and $\Lambda(1520)K^+$ system in (3) there is a structure with mass $M \simeq 2170$ MeV and width $\Gamma \simeq 110$ MeV. Both spectra have the same characteristics and can be summed. The resulting mass spectrum for $X = [\phi p + \Lambda(1520)K^+]$ is presented in Fig.1. It must be stated that the nature of the "X(2170)" structure is unclear now and needs further

study. The inverted commas in the notation of the state are used to stress this point.

The wide acceptance of the SPHINX facility has made it possible to search for heavy baryon resonances in reactions (1)–(3) in the effective mass region up to $M=4.5$ GeV and first of all for baryons with anomalously small decay widths, that can be candidates for exotic pentaquark states with hidden strangeness. There are no statistically significant heavy baryon structures with $M > 2.5$ GeV in all three mass spectra under study (i.e. for ϕp , $\Lambda(1520)K^+$ and K^+K^-p systems). Very sensitive upper limits for the cross sections of the narrow resonance production reactions have been obtained. They are given in Fig.2.

As is seen from this Figure, the experiments on the SPHINX setup failed to confirm the existence of narrow heavy baryons $R(3520)$ or nonstrange analog of $\Sigma(3170)$. For example, the SPHINX upper limits for the cross sections of $R(3520)$ production in reactions (1)–(3) are

$$\sigma_p[R(3520)]|_{nucleon} \cdot BR[R(3520) \rightarrow \phi p] \leq 0.27 \text{ nb/nucleon}, \quad (6)$$

$$\sigma_p[R(3520)]|_{nucleon} \cdot BR[R(3520) \rightarrow \Lambda(1520)K^+] \leq 3.4 \text{ nb/nucleon}, \quad (7)$$

$$\sigma_p[R(3520)]|_{nucleon} \cdot BR[R(3520) \rightarrow K^+K^-p] \leq 2.6 \text{ nb/nucleon} \quad (8)$$

(95%) C.L.). These values are by 4-5 orders of magnitude lower than the cross section of $R(3520)$ production in the pion reaction $\pi^- + p \rightarrow \rightarrow (pK^+K^*(892)^-\pi^-) + X^0$ at $P_\pi=16$ GeV, which has been claimed in Ref. [11].

3. SEARCH FOR $N_\phi(1960)$ BARYON

In the experiments with the BIS-2 setup in a neutron beam of the IHEP 70 GeV proton synchrotron with the mean energy $< E_n > \simeq 40$ GeV the reaction

$$n + N \rightarrow [\Sigma(1385)^-K^+] + N + (\text{neutral particles}), \quad (9)$$

$$\quad \quad \quad \searrow \Lambda\pi^-$$

was studied. In the effective mass spectrum of $[\Sigma(1385)^-K^+]$ a narrow peak with the mass $M = 1956^{+8}_{-9}$ MeV and the width $\Gamma = 27 \pm 15$ MeV was observed [9]. This structure was interpreted in Ref. [9] as a candidate for cryptoexotic baryon with hidden strangeness $|qqqs\bar{s}\rangle$ ($q = u$ or d). The data on the cross section of $N_\phi(1960)$ production in (9) are presented in Table 1.

Because of the importance of the problem of possible existence of cryptoexotic $|qqqs\bar{s}\rangle$ baryons we have performed a new search for this state in reaction (4) and (5) with the SPHINX setup.

Figure 1. The summed invariant mass spectrum for $X = \phi p + \Lambda(1520)K^+$ (for $P_T^2 < 0.075 \text{ (GeV)}^2$) in reactions (2) and (3). The events of ϕp and $\Lambda(1520)K^+$ type are weighted with the acceptance of the setup with account of the branchings $BR(\phi \rightarrow K^+K^-) = 0.49$ and $BR[\Lambda(1520) \rightarrow pK^-] = 0.225$.

Figure 2. Upper limits for the cross sections of the diffractive production of heavy B_ϕ baryons with $\Gamma \leq 50 \text{ MeV}$ in the decay channels $B_\phi \rightarrow K^+K^-p$, $B_\phi \rightarrow \phi p$, $B_\phi \rightarrow \Lambda(1520)K^+$ (here $BR(\phi \rightarrow K^+K^-)$ and $BR[\Lambda(1520) \rightarrow K^-p]$ are taken into account).

As the first step for this search, the reactions

$$p + N \rightarrow (\Lambda\pi^0 K^+) + N \quad (10)$$

and

$$p + N \rightarrow (\Lambda\pi^0 K^+) + N + (\text{neutral particles}) \quad (11)$$

were singled out [13,15] and for these two reactions the invariant mass spectra $M(\Lambda\pi^0)$ were studied (see Fig.3a and b). In "elastic" reaction (10) the peak of $\Sigma(1385)^0 \rightarrow \Lambda\pi^0$ is dominating and the background level under the peak is very small. For the partially-inclusive inelastic reaction (11) the $\Sigma(1385)^0$ peak is also seen quite well. The background under the peak in this case, although significantly exceeds the same one in the "elastic" reaction, is much lower than in the BIS-2 measurements for (9), where the background exceeds more than 2 times the number of the events in $\Sigma(1385)$ peak (Ref. [9]). Thus reactions (4) and (5) were identified. In the mass spectra of $M[\Sigma(1385)^0 K^+]$ in these reactions for different regions of P_T^2 we do not observe $N_\phi(1960)$ peak neither for the full spectra (for all values of P_T^2) nor for coherent processes, i.e. for $P_T^2 < 0.075 \text{ GeV}^2$ — see, for example, Fig.4a and b.

The SPHINX upper limits for the cross sections of the reactions

$$p + N \rightarrow N_\phi(1960)^+ + N \quad (12)$$

and

$$p + N \rightarrow N_\phi(1960)^+ + N + (\text{neutral particles}) \quad (13)$$

are presented in Table 1. They are significantly smaller than the BIS-2 cross sections for the $N_\phi(1960)^0$ production in (9). Strictly speaking, there are no direct contradictions between the SPHINX and the BIS-2 data because they are obtained in the distinct processes. But it seems to us, that the big difference between the values of these cross sections (see Table 1), as well as very hard background conditions for the separation of reaction (9) and $N_\phi(1960)$ state in the BIS-2 measurements give significant doubts in the real existence of $N_\phi(1960)$ baryon.

Table 1. Cross section estimations

The BIS-2 data Partially inclusive inelastic process $n + N \rightarrow N_\phi(1960) + N + (\text{neutr. particl.})$	The SPHINX data (upper limits for the cross section with 95% c.i.) "Elastic" reaction $p + N \rightarrow N_\phi(1960) + N$	Partially-inclusive inelastic reaction $p + N \rightarrow N_\phi(1960) + N + (\text{neutr. particl.})$
$\sigma[N_\phi(1960)] _C \cdot BR =$ $\begin{cases} (1.25 \pm 285) \text{ nb/C} \\ \text{or with account of factor 1.7} \\ \sim 3 \cdot 10^3 \text{ nb/C} \end{cases}$	Coherent process ($P_T^2 \leq 0.075 \text{ GeV}^2$) $\sigma[N_\phi(1960)] _C \cdot BR < 660 \text{ nb/C}$	Coherent process ($P_T^2 \leq 0.075 \text{ GeV}^2$) $\sigma[N_\phi(1960)] _C \cdot BR < 820 \text{ nb/C}$
The same cross section per 1 nucleon $\sigma[N_\phi(1960)] _{\text{nucleon}} \cdot BR =$ $\begin{cases} 330 \pm 60 \text{ nb/nucleon} \\ \text{or with account of factor 1.7} \\ \simeq 560 \text{ nb} \end{cases}$ (for $\sigma \sim A^{2/3}$)	The same cross section per 1 nucleon $\sigma[N_\phi(1960)] _{\text{nucleon}} \cdot BR <$ $< \begin{cases} 55 \text{ nb/nucleon } (\sigma \sim A) \\ 125 \text{ nb/nucleon } (\sigma \sim A^{2/3}) \end{cases}$	The same cross section per 1 nucleon $\sigma[N_\phi(1960)] _{\text{nucleon}} \cdot BR <$ $= \begin{cases} 70 \text{ nb/nucleon } (\sigma \sim A) \\ 150 \text{ nb/nucleon } (\sigma \sim A^{2/3}) \end{cases}$
	For all P_T^2 $\sigma[N_\phi(1960)] _{\text{nucleon}} \cdot BR \leq 120 \text{ nb/nucleon}$ ($\sigma \sim A^{2/3}$)	For all P_T^2 $\sigma[N_\phi(1960)] _{\text{nucleon}} \cdot BR \leq 230 \text{ nb/nucleon}$ ($\sigma \sim A^{2/3}$)

Notes:

- 1) $\sigma[N_\phi(1960)]|_C$ the cross section for the corresponding reactions per C nucleus;
- 2) $\sigma[N_\phi(1960)]|_{\text{nucleon}}$ - the same but per 1 nucleon;
- 3) $\sigma \sim A$ is possible for coherent reactions;
- 4) $BR = BR[N_\phi(1960) \rightarrow \Sigma(1385)K]$ - for all isotopic states;

5) It must be born in mind that the values for the cross sections in the experiment BIS-2 [9] were obtained not very correctly. It was shown by fitting the $[\Sigma(1385)^- K^+]$ effective mass spectrum from the BIS-2 data in the same way, as for the SPHINX data in Fig.4, that the number of the events in the N_ϕ -peak, as well as the BIS-2 cross sections must be increased by a factor of $1.7 \div 2.0$, as compared the published values in Ref. [9].

Figure 3. The invariant mass spectra for $\Lambda\pi^0$ system: a) in "elastic" diffractive production reaction (10); b) in inelastic partially-inclusive reaction (11). The parameters of $\Sigma(1385)^0$ peak are in agreement with tabulated values (with the account of the apparatus mass resolution $\sigma = \pm 9$ MeV and systematic errors). The arrows indicate the region of $\Sigma(1385)$ band.

Figure 4. Search for $N_\phi(1960)$ baryon in the mass spectra of $\Sigma(1385)^0 K^+$ system in the SPHINX setup: a) for "elastic" reaction (4) (all P_T^2); b) for inelastic partially-inclusive reaction (5) (all P_T^2). There are also no N_ϕ signals in the same spectra for coherent process (4) and (5) on carbon nuclei (i.e. for $P_T^2 < 0.075 \text{ GeV}^2$). The spectra are fitted by the sum of polynomial background and the Breit-Wigner $N_\phi(1960)$ peak with parameters of Ref. [9].

4. FURTHER ANALYSIS OF THE EFFECTIVE MASS SPECTRUM OF $\Sigma(1385)^0 K^+$ SYSTEM

Let us analyze the effective mass spectrum of $\Sigma(1385)^0 K^+$ in reaction (4). In Fig.5a this spectrum is presented for the coherent events with $P_T^2 < 0.075 \text{ (GeV)}^2$. But the form of the observed spectra does not change too much in going from the region $P_T^2 < 0.075 \text{ (GeV)}^2$ to the region of $P_T^2 > 0.075 \text{ (GeV)}^2$. There is a structure with mass $M \simeq 2060 \text{ MeV}$ and width $\Gamma \simeq 120 \text{ MeV}$ in all these spectra. The nature of this "X(2060)" structure is quite unclear. There is a feasibility of its resonance interpretation, but it also plausible to explain the form of the observed spectra by the diffractive nonresonance production mechanism with account of the Deck-effect.

This drastically calls for the determination of quantum numbers of "X(2060)" as well as the thorough study of the dynamics of reaction (4). As the first step in this direction let one analyze the role of the P_T^2 cut in singling out the coherent diffractive production process on carbon nuclei.

Basing on the study of dN/dP_T^2 distributions we have used up to now the cut $P_T^2 < 0.075 \text{ (GeV)}^2$ for the selection of coherent production reaction and the rejection of noncoherent events.

It is a soft cut which allows for more than 30% of the noncoherent background in the mass spectrum in Fig.5a. Besides, the measured value of the slope of the diffractive cone for carbon nuclei $b_1 \simeq 30 \text{ (GeV)}^2$ seems to be somewhat reduced due to the instrumental uncertainties. If the real value of b_1 is in agreement with the expected value for carbon nuclei ($\gtrsim 50 \text{ GeV}^{-2}$) then one would anticipate an additional increase of noncoherent background in this mass spectrum.

In order to reduce this noncoherent background and to obtain the $\Sigma(1385)^0 K^+$ mass spectrum for "pure" coherent production reaction a stringent requirement $P_T^2 < 0.02 \text{ (GeV)}^2$ has been used (see Fig.5b). As is seen from the comparison of the mass spectra in Figs.5a and b, under the stringent P_T^2 cut the narrow peak with mass $M = 2050 \pm 6 \text{ MeV}$ and $\Gamma = 50 \pm 19 \text{ MeV}$ is clearly observed. This narrow structure can not be explained by diffractive nonresonant process of Deck type and seems to be caused by the production of new baryon with hidden strangeness. This conclusion must be considered as preliminary and should be confirmed in further measurements with increased statistics.

Figure 5. a) The invariant mass spectrum of the $\Sigma(1385)^0 K^+$ system in the SPHINX experiment for the coherent production process (4) on carbon nuclei (i.e. at $P_T^2 < 0.075 \text{ (GeV)}^2$). The spectrum is fitted by the sum of polynomial background and the Breit-Wigner peak with $M = 2065 \pm 11 \text{ MeV}$ and $\Gamma = 118 \pm 19 \text{ MeV}$. The soft P_T^2 cut, which is used in this spectrum leads to significant noncoherent background ($\gtrsim 30\%$). b) The same spectrum, but with more stringent cut ($P_T^2 < 0.02 \text{ (GeV)}^2$) to stress the selection of coherent events. The spectrum is fitted by the sum of smooth polynomial background and the Breit-Wigner peak with $M = 2050 \pm 6 \text{ MeV}$ and $\Gamma = 50 \pm 20 \text{ MeV}$.

SUMMARY

Thus, the first results of the SPHINX experiment failed to confirm the existence of narrow heavy baryons $N_\phi(1960)$, $R(3520)$ and nonstrange analog of $\Sigma(3170)$, which were the candidates for cryptoexotic baryons. Strictly speaking there are no direct experimental contradictions between the SPHINX data and the results of previous experiments with these baryons. But it must be stressed that the upper limits for cross-sections (6)–(8) are by 4–5 orders of magnitude lower, than the cross section $\sigma(\pi^- p \rightarrow R(3520) + X^0) \cdot [BR(R \rightarrow p K^+ K^*(890)^- \pi^-)] = 14 \pm 3 \mu\text{b}$ of Ref. [11]. At the same time the background conditions for the search for $N_\phi(1960)$ baryon in coherent diffractive reaction (4) as well as in partially-inclusive nonelastic process (5) in the SPHINX facility are much better than for the corresponding measurements with the BIS-2 [9].

Thus, there are serious doubts about the real existence of the $R(3520)$ and $N_\phi(1960)$ baryons.

The preliminary data of possible observation of new baryon state $X(2050)$ with anomalously narrow decay width is also obtained in the SPHINX experiment. This state is a possible candidate for cryptoexotic pentaquark baryon with hidden strangeness.

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